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MEASUREMENTS OF THE RESPONSE OF TWO LIGHT AIRPLANES TO SONIC BOOMS

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SUMMARY

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A joint FAA-USAF-NASA investigation has been made to determine the acceleration response near the center of gravity of two light airplanes, a Piper Colt and Modified Beech C-45H, to sonic-boom overpressures varying from around 1 to 16 lb/sq ft. The test airplanes were exposed to the sonic booms while parked on the ground, in cruising flight, in turns, and in flight near stall.

Acceleration increments were less than ±0.2g in the normal, transverse, or longitudinal direction, had periods of about 0.1 second, and were damped out in less than 2 cycles. No aircraft rigid-body motions were detected and the primary source of the response to sonic booms was thought to be structural. Somewhat higher responses were measured for the Piper Colt than for the Modified Beech C-45H and were attributed to the lighter wing loading of the Colt.

Responses to the sonic booms appeared to be so small as to have no significance as regards structural loads or airplane control and generally were negligible in comparison with responses resulting from routine operations such as take-off, landing, and flight in light turbulence.

INTRODUCTION

With the increased operation of supersonic aircraft by the military and with the possibility of extensive commercial supersonic transport operation, operators of personal owner and executive type of airplanes and helicopters have become concerned that the shock waves (sonic booms) caused by aircraft flying at supersonic speeds might cause structural damage or other safety-of-flight hazards to these light aircraft.

Several different investigations have been aimed toward evaluating the effects of a wide range of sonic-boom inputs on military and commercial aircraft. (See refs. 1 to 7.) In particular, such variables as the stability of the aircraft, transient tail loads, and structural responses were studied. For military fighter aircraft flying at supersonic speeds in formation, for which condition the separation distances are small and closure rates are slow, the stability modes of the aircraft may be excited and significant transient tail loads may be imposed (refs. 3 to 7). These excitations of stability modes and excessive tail loads have not been observed during operations with commercial aircraft because the separation distances are usually greater and the closure rates are much higher (refs. 1, 2, 3, and 7). For tests in which a commercial aircraft (refs. 1, 2, and 7) was exposed to comparable sonic booms both on the ground and in flight, it was judged by occupants that the greater response occurred while the aircraft was on the ground. In both tests the induced loads were considered negligible and no significant structural damage was observed.

The effects of sonic booms on light aircraft have been briefly considered in references 8 and 9. The results of these studies indicated that the effects of sonic booms would probably not be significant. However, there have been no substantiating light-aircraft response measurements to determine possible structural damage or loss of control due to sonic-boom loadings or to subsequent pilot reactions.

Because of the lack of experimental data concerning the effects of sonic booms on personal owner and executive-type aircraft and helicopters, a joint FAA-USAF-NASA program was conducted to obtain information on the responses of light aircraft to sonic booms and the reactions of the pilots.

The four different types of test airplanes and one helicopter involved in the program were provided, maintained, and operated by the FAA. Measured airplane responses and motions were obtained from a Piper Colt and a Modified Beech C-45H. Some additional observations were made for a Piper Comanche, a Piper Apache, and a Bell 47D helicopter. A Hiller H-23D helicopter which had strain gages installed on the blades was provided, instrumented, maintained, and operated by the U.S. Army Aviation personnel. Results from tests with the Hiller H-23D helicopter and some of the observations relating to the other light aircraft in the program will be reported by the FAA.

From previous experience, it is believed that the response of a light aircraft on a given heading would be a function of its geometry and operating characteristics (wing loading, short-period stability mode, etc.) as well as of the physical properties (overpressure, wave shape, period, and wave angle) of the sonic boom. The purpose of the present paper is to present the acceleration responses and motions of the Piper Colt and Beech C-45H airplanes over a range of operating conditions for the various sonic-boom inputs.

SYMBOLS

Δa_{max} maximum positive or negative value of airplane acceleration increment for a specific sonic boom, g units

Δp_o pressure rise across shock wave at ground level, lb/sq ft

Δp_f measured free-air pressure rise across shock wave, lb/sq ft

Δp_{20}	measured pressure rise across shock wave at a height of 20 feet from ground, lb/sq ft
Δp_{est}	estimated pressure rise across shock wave at test-aircraft altitude, lb/sq ft
Δt	time interval between arrival of bow shock wave and tail shock wave, sec
Δt_{est}	estimated time interval between arrival of bow shock wave and tail shock wave at test-aircraft altitude, sec
M	airplane Mach number
μ	Mach angle, $\sin^{-1} \frac{1}{M}$
ϕ	experimentally determined shock-wave angle, deg
ϕ_{est}	estimated shock-wave angle at test-aircraft altitude, deg
θ	direction from which wind is blowing, deg
p	atmospheric pressure, lb/sq ft
T	atmospheric temperature, °F
V	wind velocity, ft/sec

APPARATUS AND METHODS

General Procedures

Simulated in the tests were flight conditions normally experienced by light aircraft flying in a routine manner in the same vicinity in which supersonic aircraft are operating. Several light aircraft were tested in the static condition on the ground and at an altitude of 5,000 feet at various operating conditions including cruise flight, turns, and flight near stall while being exposed to the shock waves from a supersonic aircraft in steady level flight at predetermined altitudes and Mach numbers. The generating airplane was flown at altitudes from 3,600 feet to 36,000 feet above mean sea level (MSL) at Mach numbers from 1.02 to 1.34. These test conditions of the generating aircraft produced peak overpressures at ground level from about 1 to 12 lb/sq ft, shock-wave angles from about 56° to 79°, and periods from about 0.06 to 0.10 second. Twenty-three flight runs were made from February 19 to 25, 1963. A summary of the operating conditions for both the generating aircraft and the two instrumented test aircraft is given in tables I to III. Radar space-position information as a function of time was obtained simultaneously for both the generating and the test airplanes, and these data were correlated with test-airplane response measurements, pilot observations, and sonic-boom measurements.

Test Site

The flight tests were accomplished in the vicinity of the Edwards Air Force Base Supersonic Flight corridor at the south end of Rogers Dry Lake in California. The terrain is generally flat with only sparse vegetation and is approximately 2,000 to 3,000 feet above mean sea level. As can be seen from the contour lines of figure 1(a), no extreme variations in elevation existed in the test area. In all tests the generating airplane was flown at steady-level-flight conditions generally along a 250° magnetic heading. The test airplanes were flown in the vicinity of runway 25-7 for the flight tests or were parked on this runway for the ground tests (fig. 1(b)).

Weather Observations

Rawinsonde observations from the Edwards Air Force Base weather facility, which was located about 7 miles from the ground pressure recording station (fig. 1(a)), were taken within 3 hours of each flight test. Measured values of temperature and pressure, along with the calculated values of speed of sound, humidity, and wind velocity and direction, were provided at 1,000-foot intervals for altitudes up to about 5,000 feet in excess of the generating-airplane altitude. Based on the foregoing measurements, estimates of the atmospheric data pertinent to the generating-aircraft altitude, test-aircraft altitude, and the ground surface in the test area during the tests are given in table IV.

Description of Aircraft

Generating aircraft.- A photograph of the type of airplane used to generate the sonic booms for these tests is shown as figure 2. These aircraft had an overall length of 55 feet and a gross weight of approximately 27,000 pounds. They were provided, maintained, and operated by U.S. Air Force personnel. The operating dates, along with conditions of Mach number, altitude, and heading for all the runs, are given in table I.

Test aircraft.- The FAA Piper Colt (fig. 3(a)) and Modified Beech C-45H (fig. 3(b)) airplanes were instrumented by NASA personnel and were the only aircraft for which response measurements were made. Planform views on which are indicated overall dimensions, wing area, wing loading, aircraft weight, and speed range, are given for the Piper Colt and Beech C-45H airplanes in figures 4(a) and 4(b), respectively.

Aircraft Positioning

The generating aircraft and one of the two instrumented test aircraft were positioned over the test area by means of ground control procedures with the aid of radar tracking facilities located approximately 8 miles north of the test area (fig. 1(a)). Radar plotting-board overlays were obtained for the generating aircraft and one instrumented test aircraft for each run listed in the tables. Plan position and altitude data obtained at 1-second intervals for the generating aircraft and 5-second intervals for the test airplane were used to provide the type of information shown in figure 5. The data of figure 5 apply directly to run 14a for which the test aircraft was on a flight-path heading generally perpendicular to that of the generating aircraft.

Plotting-board information such as that indicated in figure 5 was used to properly position the generating aircraft to provide a predetermined sonic-boom exposure in the test area and to position the test aircraft in the area at the proper time. From this type of overlay the actual plan position, altitude, and velocity of the generating and test aircraft were subsequently determined.

In order to synchronize the tracking data with both the sonic-boom pressure measurements and the airplane response measurements, a 1,000-cps tone signal was superimposed on all the data records approximately 10 seconds before the generating aircraft passed over the ground recording station.

Instrumentation

Sonic boom.- In order to provide a basis for estimating the overpressure conditions for the test aircraft, transportable ground-based sonic-boom pressure measuring equipment (fig. 6) was provided and operated by NASA personnel. This equipment was located at the intersection of runways 25-7 and 35-17 (fig. 1(b)) and consisted of 2 microphones and their associated power supply, amplifiers, and recorder. One microphone was located at approximately ground level and one was located directly above on a 20-foot-high mast. This microphone arrangement made possible the measurement of both free-air ground and reflected pressure signatures plus the angles of incidence of the shock waves. The microphones, which are commercially available condenser microphones, were specially modified in order to provide frequencies from 0.1 cps to 10,000 cps. The characteristics of this equipment were judged from past experiences (ref. 10) to be adequate to reproduce the sonic-boom signatures produced by the generating aircraft. The microphone equipment was calibrated prior to each day's test runs. The output of the microphones was recorded on a conventional multichannel oscillograph for which the recording elements had a flat frequency response from 0 to 5,000 cps.

Aircraft response.- The Piper Colt and Modified Beech C-45H were each equipped with three NASA acceleration transmitters, a Consolidated Electrodynamics flight oscillograph, a 1/10-second timer, and a gun camera. A photograph of the instruments installed in the Beech C-45H aircraft is shown as figure 7. The acceleration transmitters were oriented to measure longitudinal, normal, and transverse accelerations, had natural frequencies around 16 cps, and were from 0.6 to 0.65 critically damped. The recording galvanometers had natural frequencies of 10 cps and were 0.6 critically damped. The sensitivities of the traces of the acceleration time history ranged from 1.30 to 1.46 in./g.

The instruments were fastened to 3/8-inch-thick dural panels which were rigidly attached to the structure of the aircraft. The instrument board was fastened to the structure just under the baggage-compartment floor of the Colt and to the floor seat attachment for the right seat in the forward cabin of the C-45H. The acceleration transmitters were located near the center of gravity of the airplanes at about 55 percent mean aerodynamic chord of the Colt and

31 percent mean aerodynamic chord of the C-45H. The gun cameras were fastened to the wing strut of the Colt and under the front of the fuselage of the C-45H with the lens axis pointing forward to indicate aircraft motions. Power for the instruments was supplied by a 24-volt battery for the Colt and by the airplane system for the C-45H.

RESULTS AND DISCUSSION

Nature of Sonic-Boom Input

The profile-view geometry of the shock-wave patterns from the generating airplane is shown in figure 8. The shock waves are swept back at an angle μ depending on the Mach number, extend to the ground, and are reflected by the ground surface, as indicated by the dashed line. Therefore, the disturbance observed at a measuring station on the ground was generated prior to the time that the aircraft passed overhead but was not detected until the aircraft had passed by. For uniform sonic-boom exposures over an area on the ground, it is thus important that steady-supersonic-flight conditions be maintained for a specified distance along the flight track. This specified distance along the flight track is a function of the airplane operating conditions of Mach number and altitude. For the conditions of the present tests, the sonic booms experienced by the test aircraft were from steady level flight conditions of the generating aircraft.

As indicated schematically in figure 8, the test aircraft experienced a different sonic-boom exposure when in the air than when parked on the ground. When the test aircraft were in the air, the geometry was such that there was first an exposure to the incident waves and, at some time later, to the reflected waves which are seen to approach the test aircraft at a different angle. When the test aircraft were at ground level, these incident and reflected waves were essentially in phase and the resulting pressures were about double the free-air values.

Wave shapes.- Tracings of sample sonic-boom pressure time histories from which data were obtained are reproduced in figures 9 and 10 for both high-altitude and low-altitude flight conditions of the generating aircraft to illustrate some of the physical phenomena involved and to define some of the symbols used. The pressure time histories from run 1 as obtained at ground level and on a 20-foot-high mast (as indicated in the sketch) for a high-altitude pass are presented in figure 9. Since the time history of figure 9(a) was made at ground level, the incident and reflected waves are coincident. On the other hand, the tracing obtained on the top of the 20-foot-high mast as shown in figure 9(b) contains distinct incident and reflected wave components.

When the generating airplane is operating at low altitudes, the wave shapes vary from the classical N-wave shape of figure 9(a). In order to illustrate this variation, time histories for run 14a are shown in figure 10. It can be noted from figure 10(a) that additional peaks occur in the record about midway between the first and last pressure rise. These additional pressure rises were found to be associated with the geometry of the airplane and in particular with the wing. (See refs. 1 and 10.)

Peak pressures.- Measured values of the overpressures, as defined in figure 9, for all of the runs are presented in table I. Shown also for comparison are the theoretical values calculated for the test Mach numbers and altitudes by the far-field relations of reference 11 in the form presented in reference 12.

The measured ground pressure data for all tests for the on-the-track conditions are plotted in figure 11 as a function of the generating-airplane altitude. It can be seen that the pressures measured at the ground range from about 12 lb/sq ft at an altitude of 3,600 feet MSL to about 1 lb/sq ft at 36,000 feet MSL. The measured data are seen to be in good agreement with the calculations. Thus, the theory of reference 11 is useful for making estimates of the overpressures for this type of generating aircraft at these test altitudes and was used as a basis for estimating the overpressures on the test aircraft for conditions where direct measurements were not made. These estimated overpressures on the two test aircraft for all the test conditions are noted to vary from about 1 lb/sq ft to about 16 lb/sq ft, as given in tables II and III.

Shock-wave angles.- Shock-wave angles, measured with the aid of the microphone array sketched in figure 9, are listed in table I along with calculated Mach angle values for a homogeneous atmosphere. The measured values of ϕ are seen to be in good agreement with the calculated values of μ; this agreement thus indicates that the atmospheric temperature and wind effects on shock-wave propagation are small. The estimated shock-wave angles experienced by the two test aircraft are noted to vary in magnitude from about 55° to 79°. (See tables II and III.)

Periods.- Both measured and calculated values (see refs. 11 and 12) of the periods of the generating-aircraft pressure time histories Δt (as defined in fig. 9(a)) are included in table I for all the runs. It can be seen that, in general, the calculated values are in good agreement with those measured. Estimates of periods of the shock waves to which the test aircraft were exposed, based on calculated values adjusted for the test aircraft speed and direction of flight, are noted to vary from about 0.035 to 0.120 in tables II and III.

Aircraft Responses

Acceleration time histories.- Examples of the acceleration responses of the Piper Colt and Beech C-45H airplanes due to exposure to sonic booms are shown in figures 12 and 13. In each example three acceleration time histories are shown: longitudinal, transverse, and normal. The results shown in figure 12 for the responses of the aircraft in flight were obtained during run 14a for which the overpressure was 16.20 lb/sq ft and those shown in figure 13 for the responses of the parked aircraft are from run 10a for which the overpressure was 11.72 lb/sq ft. (See tables II and III.) Most of the acceleration traces contain high-frequency (>10 cps) low-amplitude acceleration associated with the airplane engine-induced vibrations. In some instances, acceleration response to the sonic boom was barely discernible from this residual acceleration level in the airplane.

For those instances where discernible accelerations were recorded (fig. 12(a), for example) the response has a sinusoidal-type waveform with a period of about

0.1 second and, generally, is damped out in less than 2 cycles. Whether these accelerations are due primarily to airplane structural responses or to a combination of structural and rigid body responses is not definitely known. It is thought, however, that structural responses are the primary source. This premise is supported by the fact that no rigid-body motions (roll, pitch, and yaw) could be detected from examination of the motion pictures taken by the gun camera. The time durations of the sonic-boom signatures (Δt_{est} = 0.035 to 0.120 sec in table III) are small compared with the periods of the so-called short-period modes of the aircraft (approximately 1.7 sec for the C-45H) and, hence, very little excitation of these modes would be expected. Furthermore, the maximum material velocities behind the shock waves were estimated to be about 6 ft/sec for these test conditions. If it is assumed that this material velocity reacted on the airplane in a vertical direction, it would be equivalent to a 6 ft/sec gust and would correspond to a maximum angle-of-attack change of 3°. Whatever the source, the acceleration responses appear to be so small as to be insignificant with regard to airplane structural loads or control.

For the in-flight condition of figure 12(a) the time of passage of both the incident and reflected shock waves as defined in figure 8 is shown. The response to the reflected wave is smaller than that to the incident wave and in the reverse direction, as would be expected. For this specific condition, the reflected waves arrived about 2.5 seconds after the incident waves. Both the incident and reflected waves strike the parked airplane on the ground essentially at the same time (fig. 8) and, consequently, only one shock-wave passage is indicated in figure 13.

Peak acceleration values.- Maximum positive and negative values of the normal, transverse, and longitudinal accelerations were determined from time histories, such as those of figures 12 and 13, and are given in tables II and III for the Piper Colt and Modified Beech C-45H airplanes, respectively. These acceleration data are also plotted as a function of sonic-boom overpressure for both the in-flight (fig. 14) and ground (fig. 15) conditions to illustrate some of the main findings of the investigation. The circle and square symbols, respectively indicate that the heading of the test airplane is either parallel to or perpendicular to that of the generating aircraft.

The maximum measured accelerations near the center of gravity of the test airplanes are seen to be less than ±0.2g in any direction. Although considerable scatter in these data exists, there is a general trend toward increased acceleration response as the overpressure increases.

The relative orientation of the aircraft and the shock wave is seen to be very significant with respect to the measured longitudinal and transverse acceleration values. In particular, the transverse accelerations were largest and the longitudinal accelerations were smallest when the advance of the shock front was perpendicular to the test aircraft heading, whereas the reverse was true when the advance of the shock front was parallel to the test aircraft heading. The normal-acceleration measurements did not seem to be sensitive to airplane orientation for the range of test conditions studied.

Comparison of the responses of the Colt airplane (figs. 14(a) and 15(a)) with those of the Modified C-45H airplane (figs. 14(b) and 15(b)) shows that the accelerations were somewhat higher on the Colt than on the C-45H. This difference in response is thought to be mainly due to the lighter wing loading of the Colt (11.2 lb/sq ft compared with 26.3 lb/sq ft).

Inspection of tables II and III indicates that the largest in-flight acceleration, 0.16g, occurred for the Colt aircraft during run 18a. In this run, the aircraft was subjected to an overpressure of about 11 lb/sq ft while operating close to the stall speed. Even for this high overpressure and flight condition where the aircraft was considered to be most susceptible to loss of control, the responses were of little consequence. For the same test conditions, the responses of the C-45H airplane were barely detectable.

Comparison of sonic-boom-induced responses with those induced by other inputs.- In order to indicate the magnitude of the sonic-boom responses relative to other responses resulting from routine operations, acceleration time histories recorded during take-off and landing operations, flight in light turbulence, and during the sonic-boom tests are presented in figures 16 and 17. Examination of these figures indicates that the responses to the sonic boom in almost every run are small in comparison with the acceleration responses resulting from runway roughness during take-off and landing and by flight in light turbulence. The time histories of accelerations measured during the ground run in take-off and landing do not include lift-off and landing impact. Only in the transverse accelerations during run 10b did the magnitude of the responses approach the magnitudes of accelerations experienced in routine operations. It would appear, therefore, that the sonic-boom-induced responses are, for the most part, negligible in comparison with responses resulting from normal routine operations.

CONCLUDING REMARKS

A flight investigation has been conducted to measure the acceleration responses of a Piper Colt and a Modified Beech C-45H airplane to sonic-boom overpressures varying from about 1 to 16 lb/sq ft. The airplanes were exposed to the overpressures while parked on the ground, in cruising flight, in turns, and in flight near stall.

Acceleration increments measured near the center of gravity were less than ±0.2g in the normal, transverse, or longitudinal direction, had periods of about 0.1 second, and generally were damped out in less than 2 cycles. Some responses from the booms were not discernible from the residual acceleration level. Airplane rigid-body motions were not detected from motion pictures and the primary source of the response was thought to be structural. Somewhat higher responses were measured for the Piper Colt than for the Modified Beech C-45H and were attributed to the lighter wing loading of the Colt.

In general, the magnitude of the acceleration response increased with overpressure, was dependent on the orientation of the shock wave and test aircraft, and apparently was somewhat higher in flight close to stall than in cruise or turning flight.

The responses to the sonic booms appeared to be so small as to be insignificant as regards structural loads or airplane control and were, for the most part, negligible in comparison with responses resulting from routine operations such as take-off, landing, and flight in light air turbulence.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., May 10, 1963.

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TABLE I.- SUMMARY OF OPERATING CONDITIONS AND ASSOCIATED SHOCK-WAVE PARAMETERS FOR GENERATING AIRPLANE

Run	Date	M	Altitude from MSL, ft	Magnetic heading, deg	Boom time	Airplane lateral distance, ft	Calculated Δt, sec	Calculated Δp_o, lb/sq ft	Shock-wave parameters					
									Measured Δp_o, lb/sq ft	Δp_f, lb/sq ft	Δp_{20}, lb/sq ft	Δt, sec	Shock-wave angle, ϕ, deg	Mach angle, μ, deg
1	Feb. 19, 1963	1.34	36,080	241	9:09 a.m.	2,600 South	0.110	1.00	0.81	0.44	0.72	0.104	63.2	48.2
2		1.25	23,220	250	9:17 a.m.	0	.097	1.83	1.45	.89	1.14	.093	59.6	53.3
3		1.19	8,335	246	1:34 p.m.	0	.069	5.98	7.24	3.50	4.44	.072	59.0	57.3
4		1.05	5,720	248	1:39 p.m.	250 North	.089	7.94	9.00	5.76	6.88	.073	66.2	72.1
6	Feb. 20, 1963	1.34	22,510	247	9:02 a.m.	500 South	.094	1.99	1.76	1.03	1.27	.085	56.9	48.3
7		1.14	11,400	248	8:55 a.m.	150 North	.088	3.98	3.13	1.62	2.48	.081	65.5	61.0
8		1.11	6,620	248	10:37 a.m.	400 South	.075	7.45	5.53	2.77	4.36	.077	64.2	63.2
9		1.11	4,480	247	10:33 a.m.	150 North	.064	12.25	9.04	4.73	6.58	.069	65.6	64.4
11	Feb. 21, 1963	1.29	25,900	249	8:51 a.m.	2,200 South	.100	1.59	1.72	0.88	1.35	.095	58.1	50.7
12		1.25	16,760	251	8:58 a.m.	250 North	.085	2.75	3.20	1.85	2.30	.080	56.4	53.3
13		1.15	9,820	247	1:30 p.m.	400 North	.078	4.99	4.03	2.03	3.04	.080	64.6	60.6
14		1.15	7,540	248	11:10 a.m.	0	.072	6.46	5.40	2.83	3.37	.069	59.5	60.2
14a		1.18	5,560	248	11:17 a.m.	600 South	.061	9.72	8.43	4.20	5.56	.064	59.6	58.5
16		1.19	16,400	248	1:36 p.m.	1,300 South	.090	2.71	2.99	1.82	2.28	.087	60.3	57.3
17	Feb. 25, 1963	1.17	9,960	250	9:36 a.m.	0	.078	4.74	3.77	1.83	2.74	.078	60.3	59.2
18		1.18	7,740	250	9:42 a.m.	0	.070	6.48	5.00	2.47	3.34	.075	61.2	58.0
18a		1.14	6,090	248	9:48 a.m.	0	.067	8.50	6.80	3.41	4.66	.072	60.3	62.0
21		1.18	9,850	247	10:42 a.m.	100 South	.078	4.94	4.30	2.53	3.66	.080	61.7	58.5
22		1.18	7,910	246	10:48 a.m.	500 South	.071	6.36	5.53	3.13	4.06	.087	62.9	58.5
23		1.15	6,300	246	10:54 a.m.	300 South	.067	8.22	7.02	4.04	5.36	.072	60.3	60.2
10		1.09	4,400	246	1:15 p.m.	0	.066	12.22	10.68	6.24	9.25	.072	69.8	67.2
10a		1.05	4,300	245	1:21 p.m.	200 North	.078	12.35	11.72	6.03	10.46	.079	73.4	72.5
10b		1.02	3,600	245	1:29 p.m.	0	.092	15.50	11.10	-----	------	.078	----	79.0

TABLE II.- SUMMARY OF OPERATING CONDITIONS, ASSOCIATED SONIC-BOOM INPUTS,

AND RESPONSE FOR PIPER COLT AIRPLANE

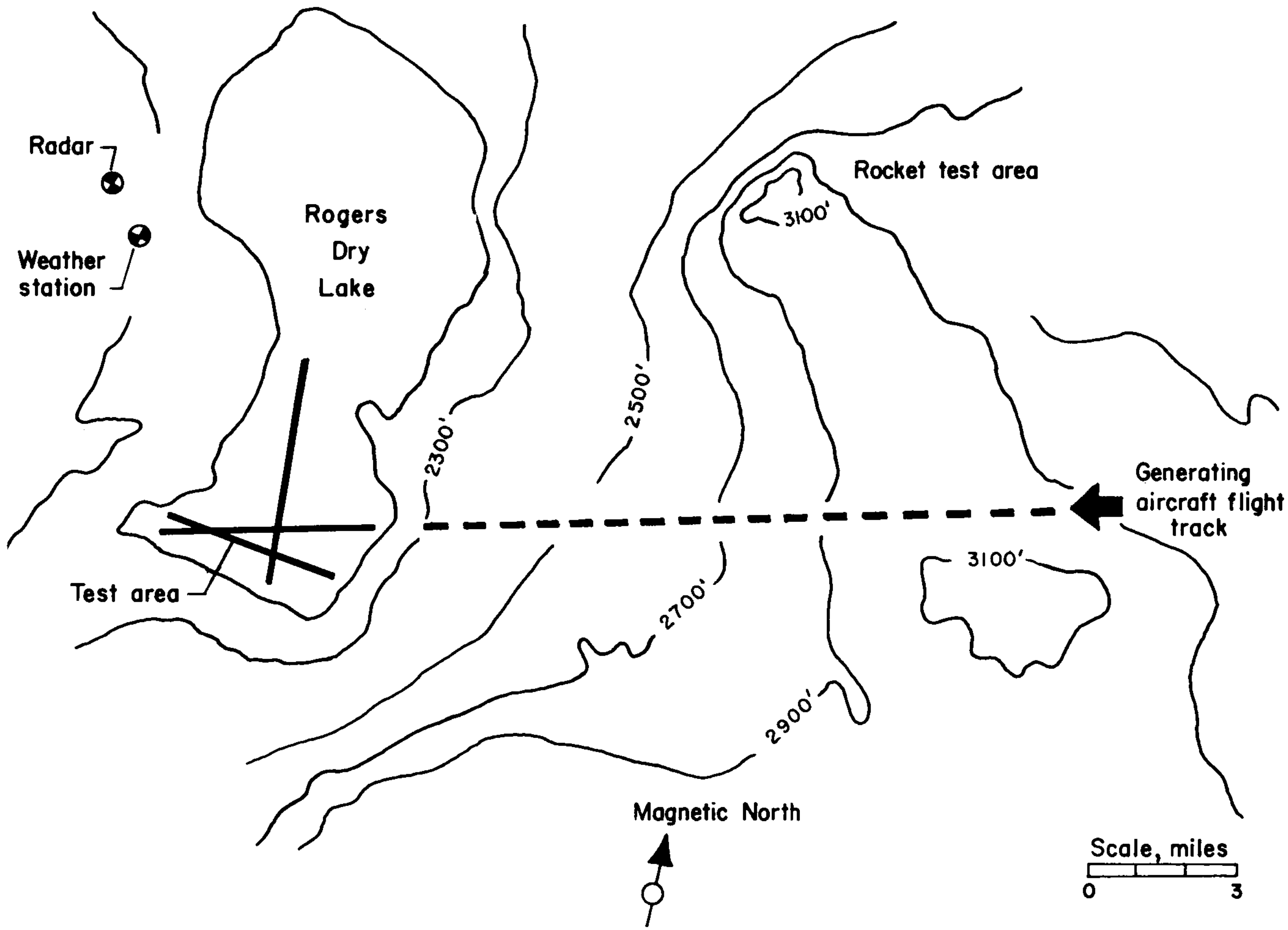
Run	Date	Test condition	Test-airplane altitude from MSL, ft	Test-airplane velocity, ft/sec	Test-airplane magnetic heading, deg	Generating-airplane magnetic heading, deg	Δp_{est}, lb/sq ft	Δt_{est}, sec	ϕ_{est}, deg	Measured Δa_{max}, g units			Boom heard in test airplane
										Longitudinal	Transverse	Normal	
1	Feb. 19, 1963	On ground	2,300	0	068	241	0.81	0.104	63.2	0	0	0	Yes
2			2,300	0	068	250	1.45	.093	59.6	0	0	0	Yes
3			2,300	0	063	246	7.24	.072	59.0	.02	0	.02	Yes
4			2,300	0	063	248	9.00	.073	66.2	.05	.01	.02	Yes
6	Feb. 20, 1963	On ground	2,300	0	250	247	1.76	.085	56.9	0	0	0	Yes
7			2,300	0	250	248	3.13	.081	65.5	.01	.02	.01	Yes
8			2,300	0	250	248	5.53	.077	64.2	0	0	.02	Yes
9			2,300	0	250	247	9.04	.069	65.6	.04	0	.02	Yes
11	Feb. 21, 1963	Cruise	5,000	138	320	249	0.91	.105	56.0	0	0	0	Yes
12			5,000	139	260	251	1.68	.098	55.0	0	0	.02	Yes
13			4,900	137	250	247	3.53	.079	62.0	.02	0	.06	Yes
14			4,860	131	250	248	4.16	.071	60.0	.02	.02	.04	Yes
14a			4,860	131	170	248	16.20	.043	59.0	.01	.08	.07	Yes
16		Near stall	4,900	91	235	248	1.66	.092	59.0	0	0	0	Yes
17	Feb. 25, 1963	Near stall	4,960	84	255	250	3.50	.075	60.0	.01	0	.07	Yes
18			4,960	74	150	250	5.56	.058	60.0	0	.02	.06	Yes
18a			4,960	81	245	248	11.10	.054	61.0	.04	0	.16	Yes
21		360° turn	4,960	117	300	247	3.59	.066	60.0	.02	0	.05	Yes
22			4,960	125	070	246	4.46	.057	60.0	0	0	.02	Yes
23			4,960	132	060	246	6.64	.049	60.0	.01	0	.05	Yes
10		On ground	2,300	0	150	246	10.68	.072	69.8	No record taken			Yes
10a			2,300	0	150	245	11.72	.079	73.4	.01	.13	.04	Yes
10b			2,300	0	150	245	11.10	.078	79.0	.01	.19	.04	Yes

TABLE III.- SUMMARY OF OPERATING CONDITIONS, ASSOCIATED SONIC-BOOM INPUTS, AND RESPONSE FOR MODIFIED BEECH C-45H AIRPLANE

Run	Date	Test condition	Test-airplane altitude from MSL, ft	Test-airplane velocity, ft/sec	Test-airplane magnetic heading, deg	Generating-airplane magnetic heading, deg	Δp_{est}, lb/sq ft	Δt_{est}, sec	ϕ_{est}, deg	Measured Δa_{max}, g units: Longitudinal	Transverse	Normal	Boom heard in test airplane
1	Feb 19, 1963	On ground	2,300	0	160	241	0.81	0.104	63.2	0	0	0	Yes
2			2,300	0	160	250	1.45	.093	59.6	0	0	0	Yes
3			2,300	0	160	246	7.24	.072	59.0	0	.02	0	Yes
4			2,300	0	160	248	9.00	.073	66.2	0	.02	.01	Yes
6	Feb. 20, 1963	On ground	2,300	0	155	247	1.76	.085	56.9	0	0	0	Yes
7			2,300	0	155	248	3.13	.081	65.5	0	.01	0	Yes
8			2,300	0	155	248	5.53	.077	64.2	0	.02	0	Yes
9			2,300	0	155	247	9.04	.069	65.6	.01	.03	.01	Yes
11	Feb. 21, 1963	Cruise	5,000	254	250	249	0.91	.120	56.0	0	0	0	No
12			4,920	254	175	251	1.37	.084	55.0	0	0	0	No
13			5,000	240	070	247	3.53	.060	62.0	0	0	0	Yes
14			5,000	228	070	248	5.65	.054	60.0	.01	0	.01	Yes
14a			5,000	228	070	248	16.20	.035	59.0	.02	0	.02	Yes
16		Near stall	5,000	152	070	248	1.66	.076	59.0	0	0	0	Yes
17	Feb. 25, 1963	Near stall	5,000	152	340	250	3.50	.070	60.0	0	0	0	Yes
18			5,000	135	070	250	5.92	.053	60.0	.02	0	0	Yes
18a			5,000	102	090	248	11.10	.046	61.0	.02	0	0	Yes
21		360° turn	5,000	111	090	247	3.59	.064	60.0	.01	0	0	Yes
22			5,000	135	120	246	5.40	.059	60.0	.01	0	.01	Yes
23			5,000	118	270	246	10.30	.059	60.0	0	.02	.01	Yes
10		On ground	2,300	0	160	246	10.68	.072	69.8	0	.05	0	Yes
10a			2,300	0	160	245	11.72	.079	73.4	0	.04	0	Yes
10b			2,300	0	160	245	11.10	.078	79.0	0	.05	0	Yes

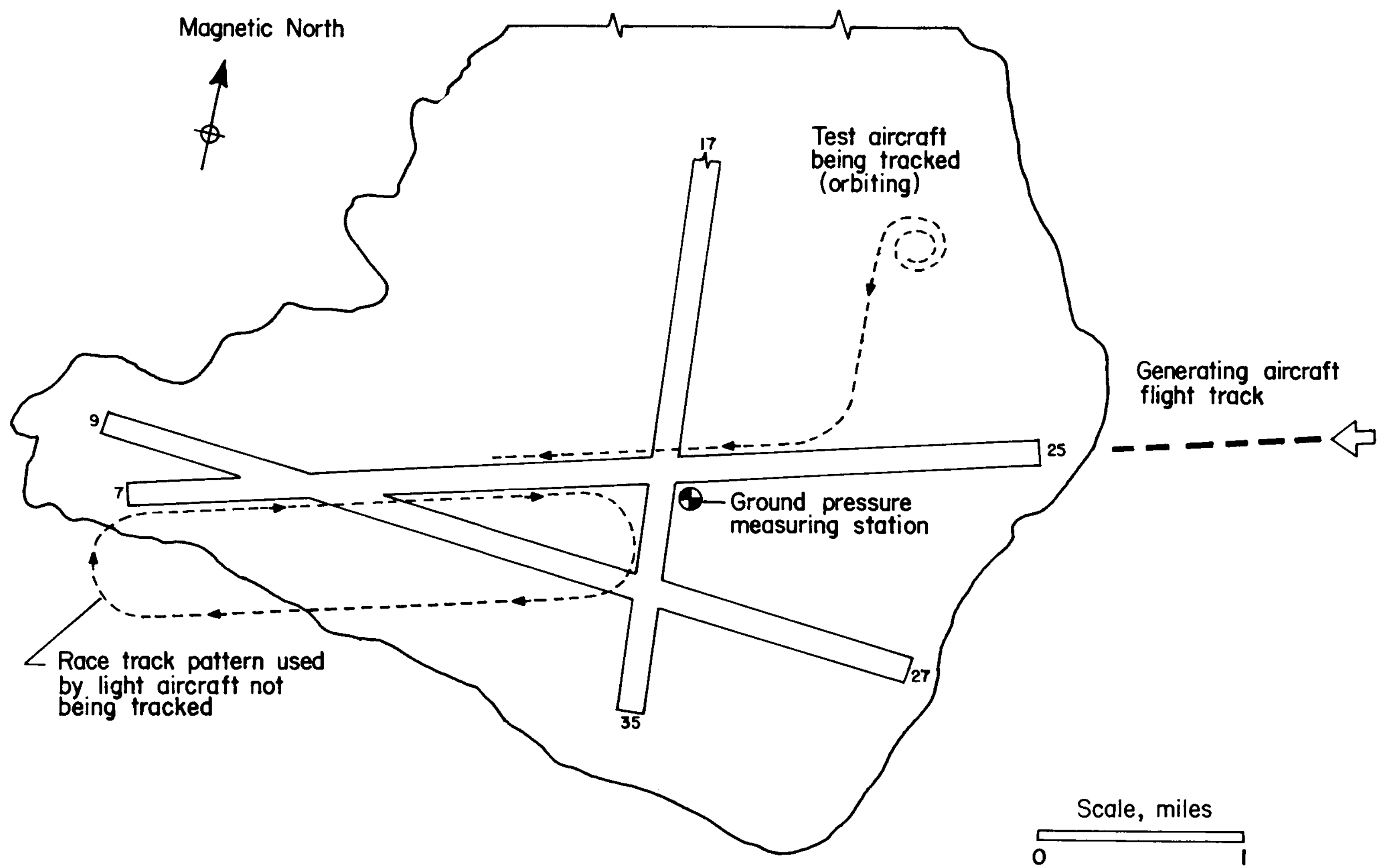
TABLE IV.- SUMMARY OF ESTIMATED ATMOSPHERIC DATA

Date	Run	Conditions at generating-airplane altitude				Conditions at test-airplane altitude				Conditions at ground level			
		p, lb/sq ft	T, °F	V, ft/sec	θ, °magnetic	p, lb/sq ft	T, °F	V, ft/sec	θ, °magnetic	p, lb/sq ft	T, °F	V, ft/sec	θ, °magnetic
Feb. 19, 1963	1	498	-67	81	304	1,964	45	0	0	1,964	45	0	0
	2	885	-20	52	317	1,964	47	0	0	1,964	47	0	0
	3	1,566	41	22	066	1,964	60	8	0	1,964	60	8	0
	4	1,719	47	23	110	1,964	60	8	0	1,964	60	8	0
Feb. 20, 1963	6	904	-8	85	272	1,954	47	10	266	1,954	47	10	266
	7	1,424	30	39	259	1,954	47	10	266	1,954	47	10	266
	8	1,652	46	27	280	1,953	62	12	266	1,953	62	12	266
	9	1,812	50	30	276	1,953	62	12	266	1,953	62	12	266
Feb. 21, 1963	11	766	-35	10	317	1,780	46	17	047	1,960	52	10	256
	12	1,142	1	70	346	1,780	46	17	047	1,960	52	10	256
	13	1,501	31	58	359	1,780	46	17	047	1,960	62	10	256
	14	1,621	40	25	353	1,780	46	17	047	1,960	52	10	256
	14a	1,746	43	17	024	1,780	46	17	047	1,960	52	10	256
	16	1,142	3	69	347	1,780	46	17	047	1,960	52	10	256
Feb. 25, 1963	17	1,482	37	25	308	1,786	57	11	099	1,960	50	7	056
	18	1,598	46	15	204	1,786	57	11	099	1,960	51	7	056
	18a	1,721	54	7	115	1,786	57	11	099	1,960	51	7	056
	21	1,545	37	29	280	1,786	57	11	128	1,960	52	7	056
	22	1,600	46	17	266	1,786	57	11	128	1,960	52	14	056
	23	1,703	50	9	206	1,786	57	11	128	1,962	52	14	056
	10	1,830	57	19	112	1,962	60	14	056	1,962	60	14	056
	10a	1,830	57	20	107	1,962	62	14	056	1,962	62	14	056
	10b	1,885	57	20	086	1,962	62	14	056	1,962	62	14	056



(a) General layout.

Figure 1.- Arrangement of test facilities and equipment.



(b) Details of test area.

Figure 1.- Concluded.

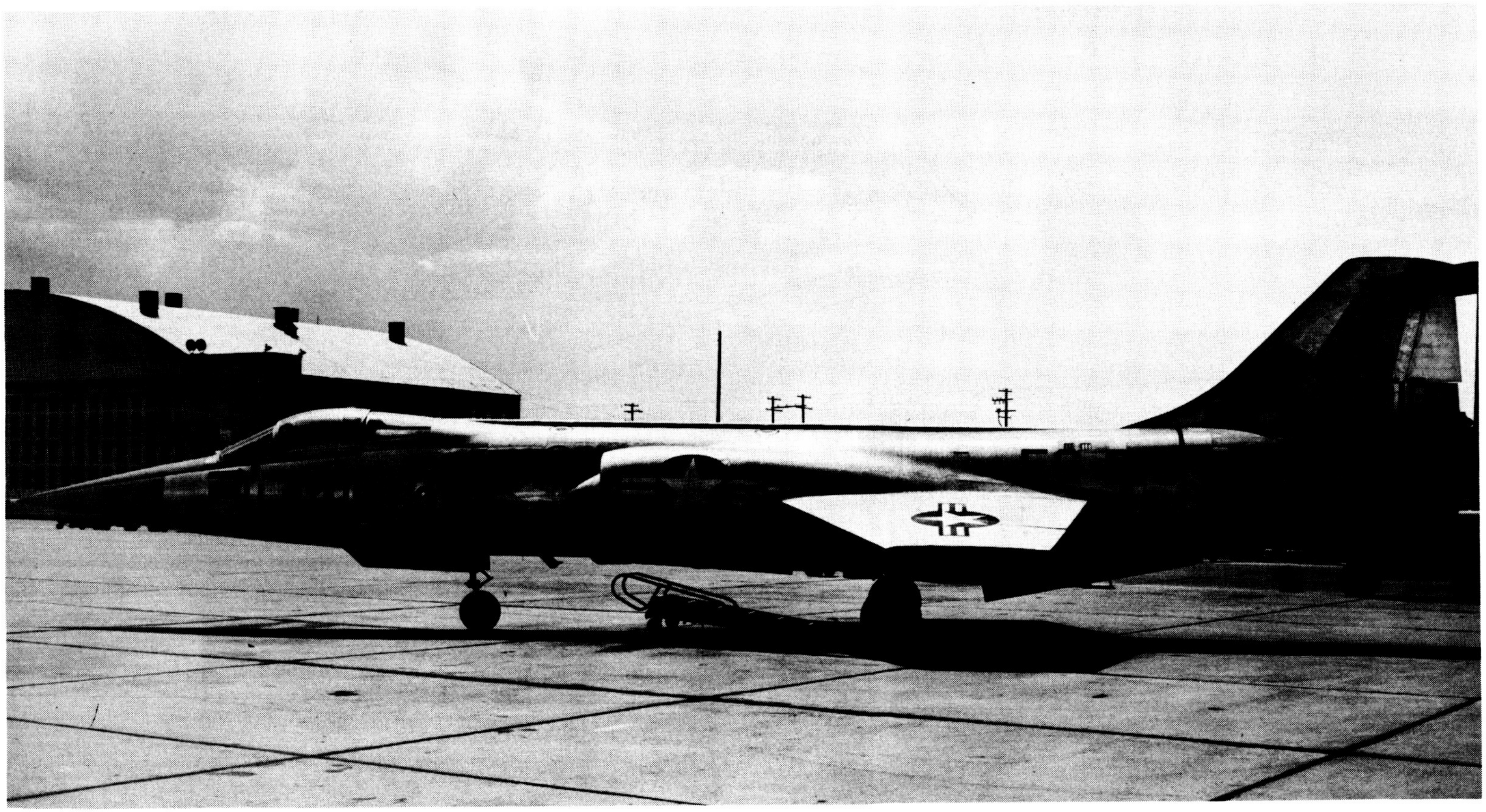


Figure 2.- Type of airplane used to generate sonic booms. L-63-3137

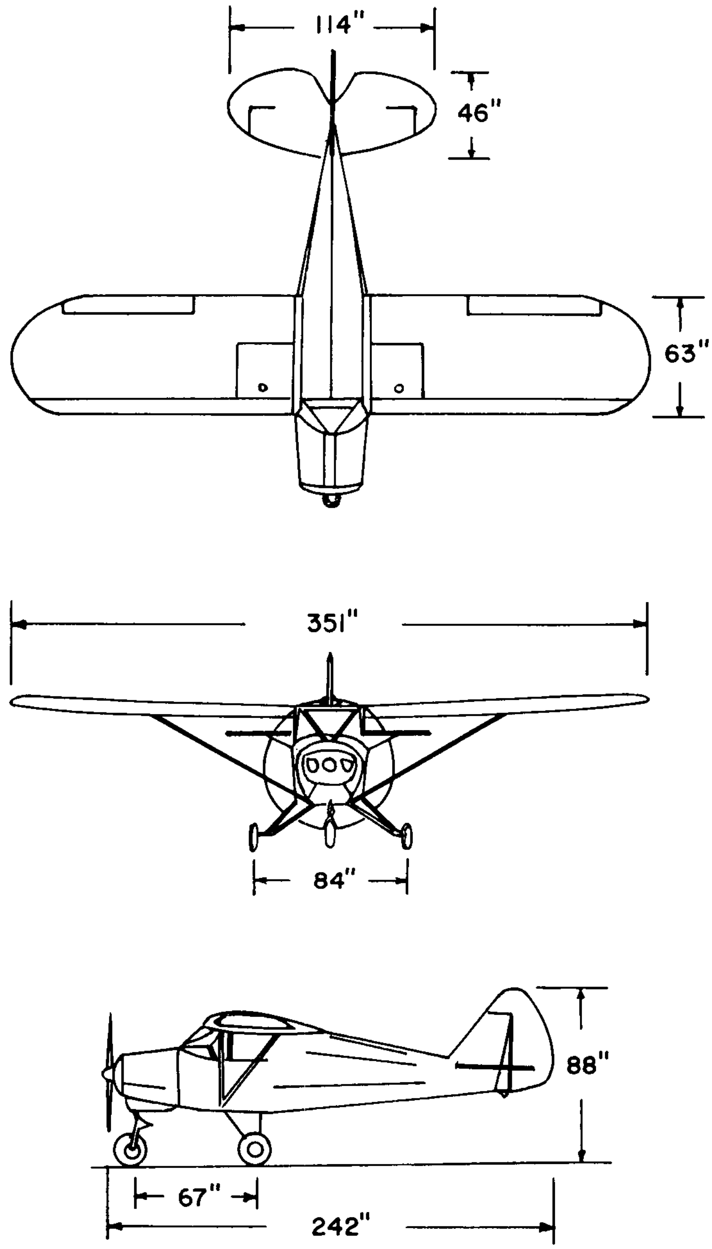
(a) Piper Colt. L-63-3138

Figure 3.- Personal owner type airplanes instrumented for the investigation.

(b) Modified Beech C-45H. L-63-3139

Figure 3.- Concluded.

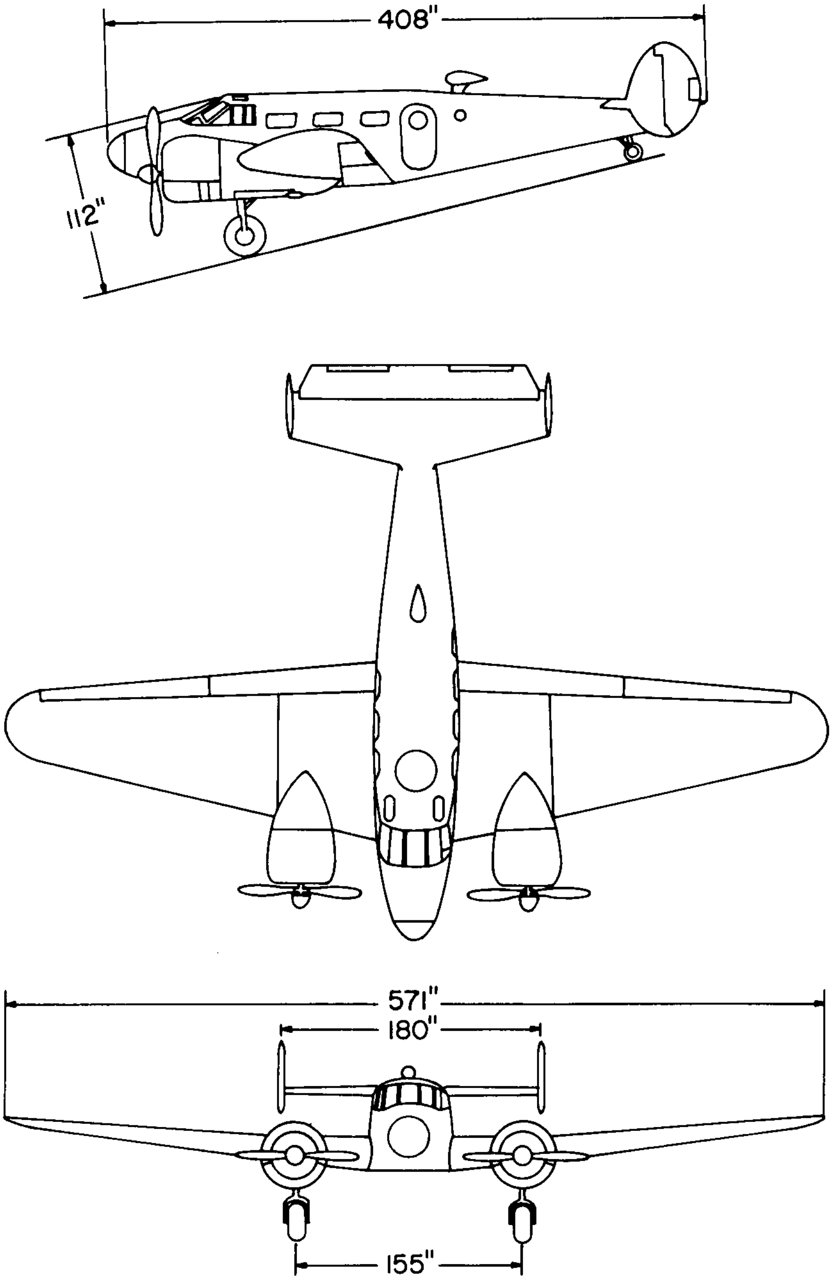
Gross weight, 1650 lb
Wing area, 147 sq ft
Wing loading, 11.2 lb/sq ft
Speed range, 54 to 120 mph



(a) Piper Colt.

Figure 4.- Three-view drawing of the test airplanes.

Gross weight, 9300 lb
Wing area, 353 sq ft
Wing loading, 26.3 lb/sq ft
Speed range, 64 to 210 mph



(b) Modified Beech C-45H.

Figure 4.- Concluded.

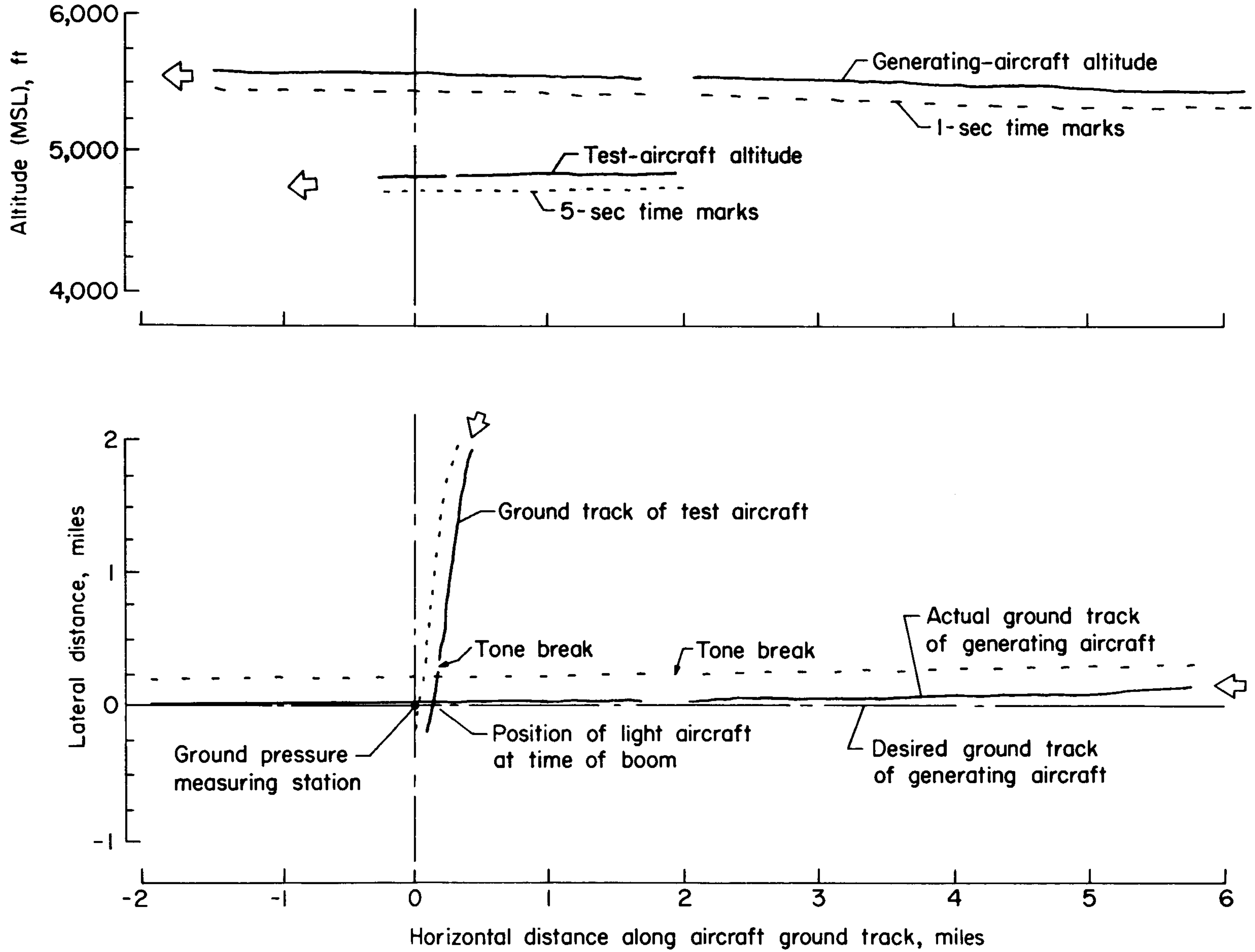


Figure 5.- Radar overlay showing plan position and altitudes of generating airplane and Piper Colt for run 14a.

Figure 6.- Transportable ground-based equipment for sonic-boom pressure measuring station. L-63-3140

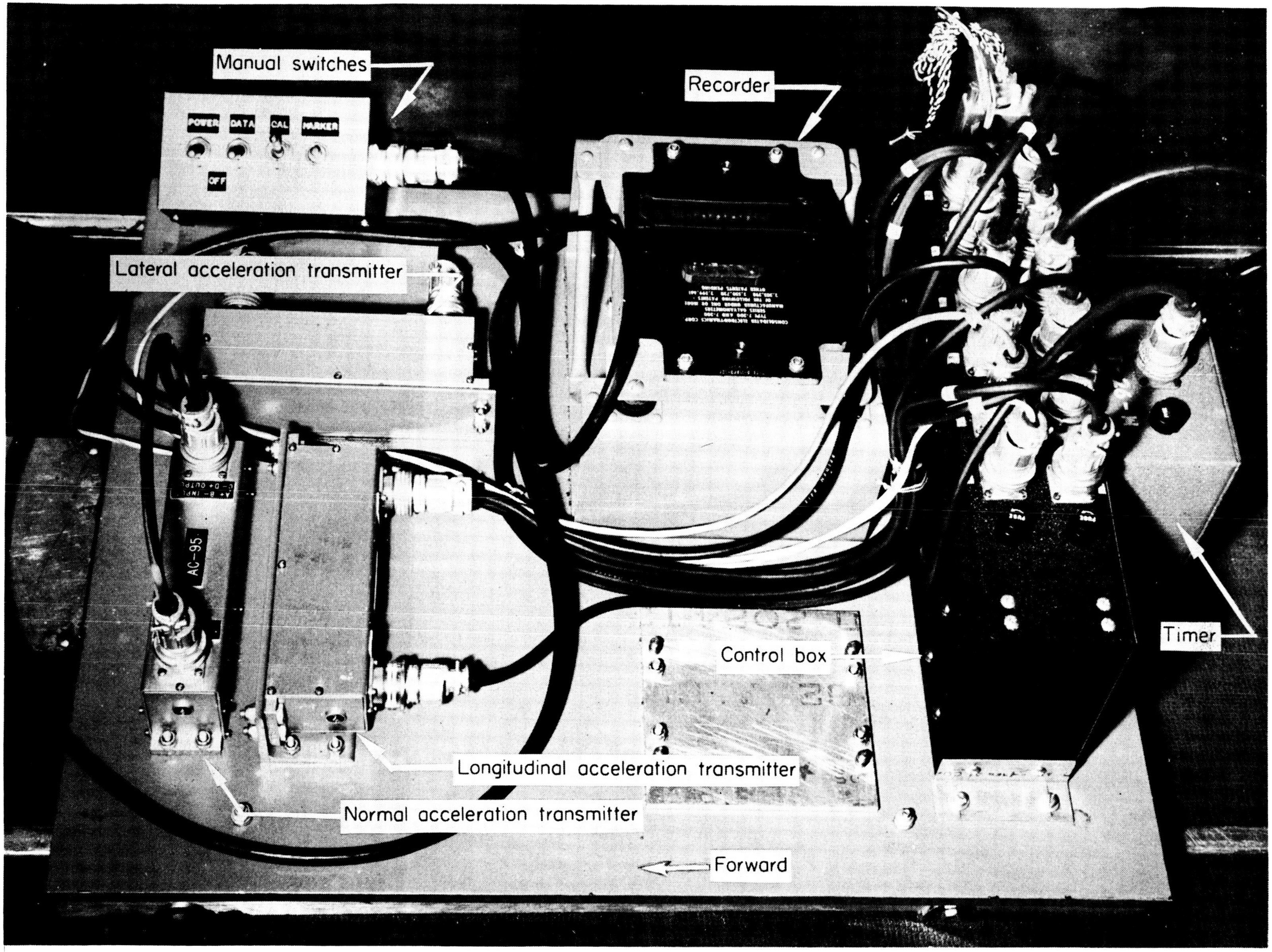


Figure 7.- Instruments installed in test aircraft. L-63-3141

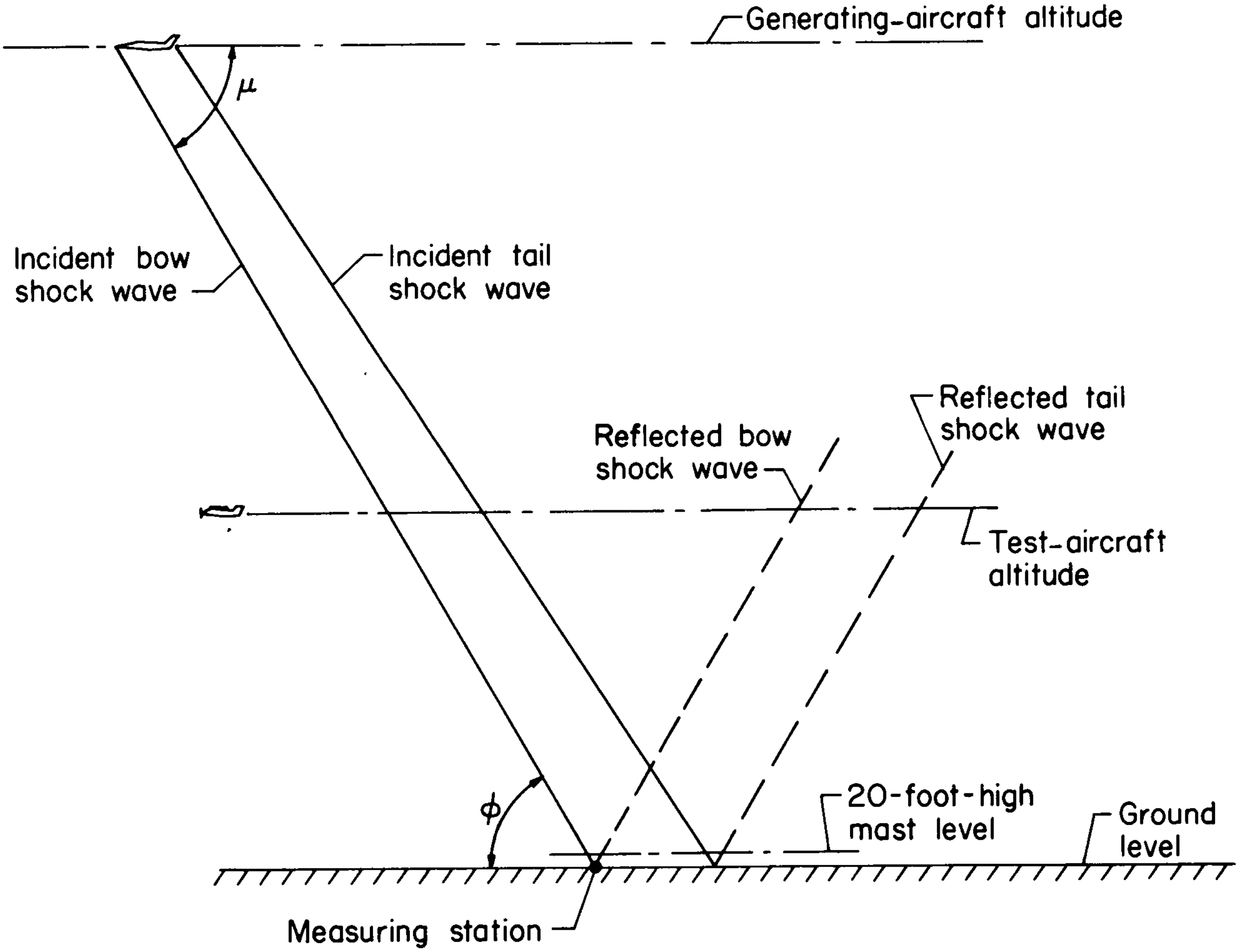
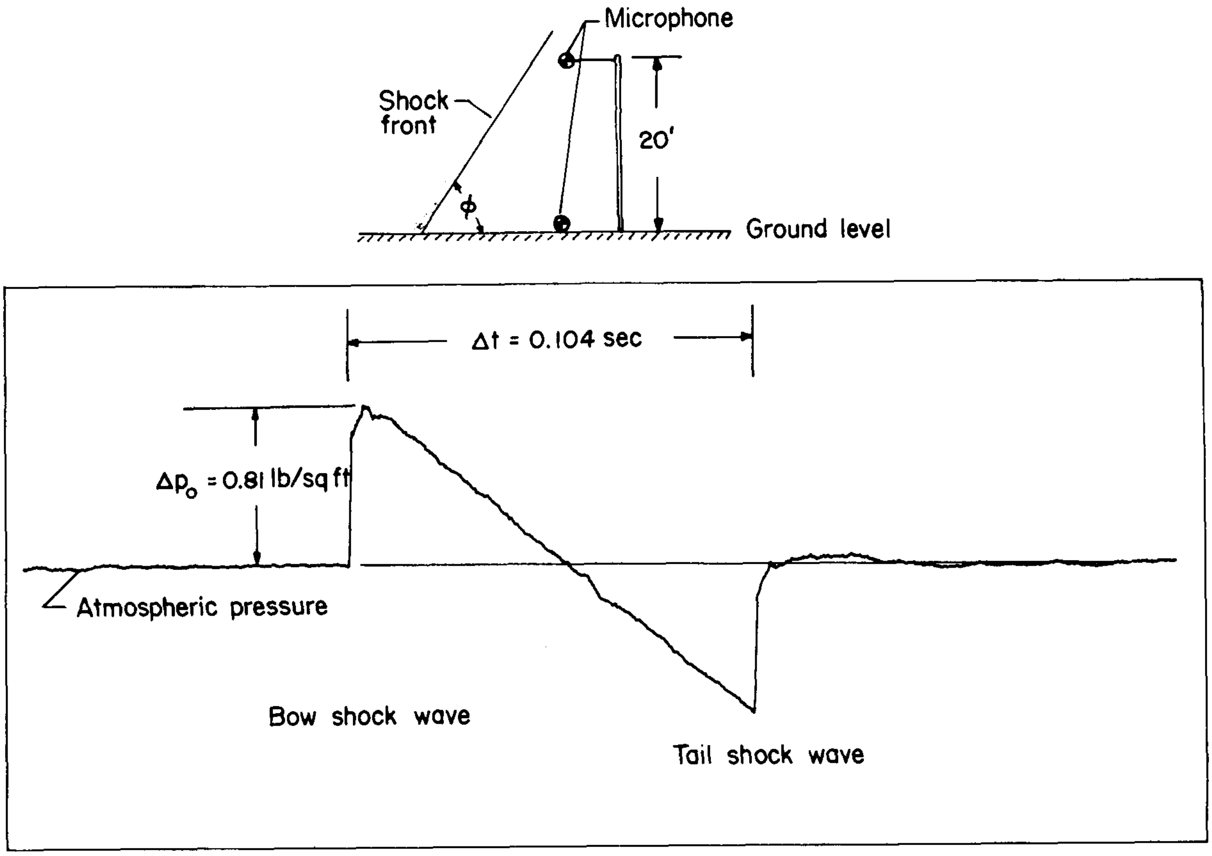
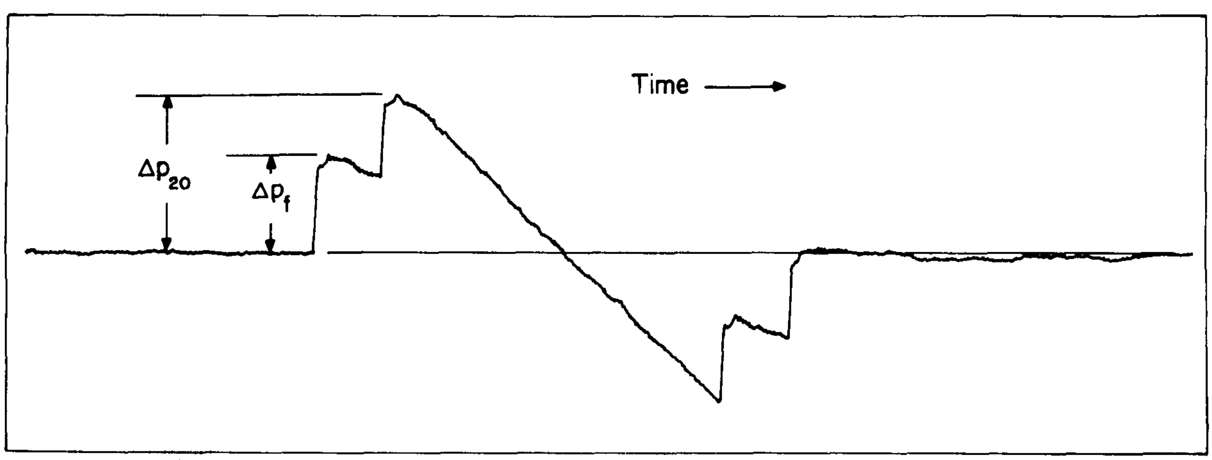


Figure 8.- Profile-view geometry of shock-wave patterns from generating airplane.

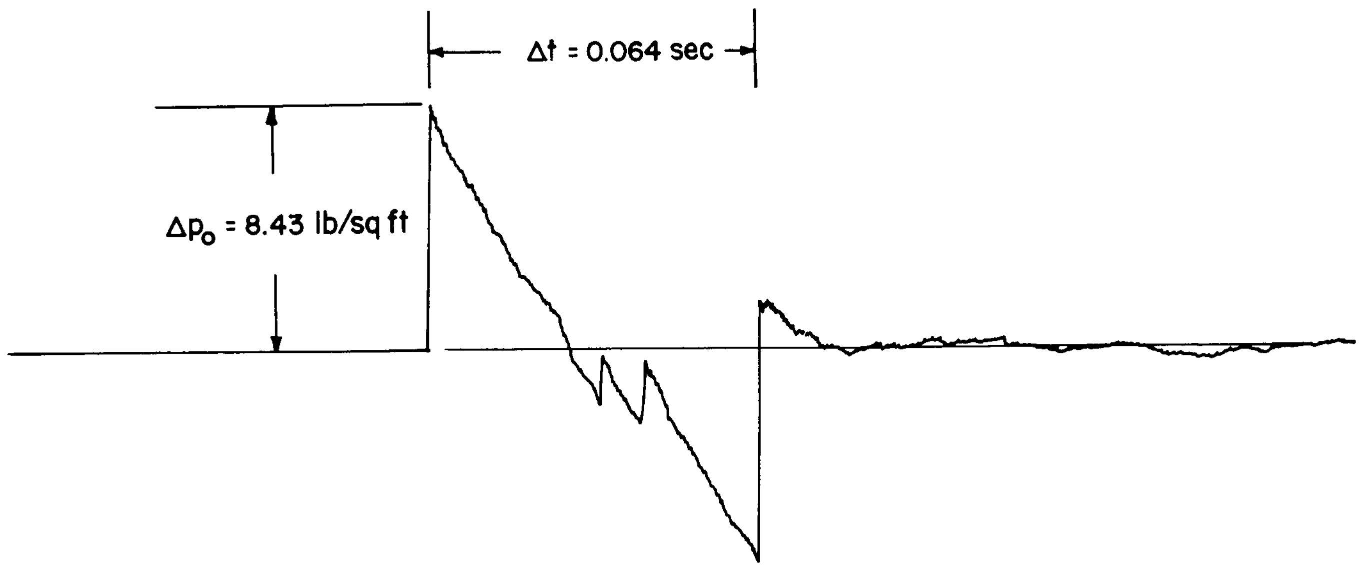


(a) Microphone on ground.

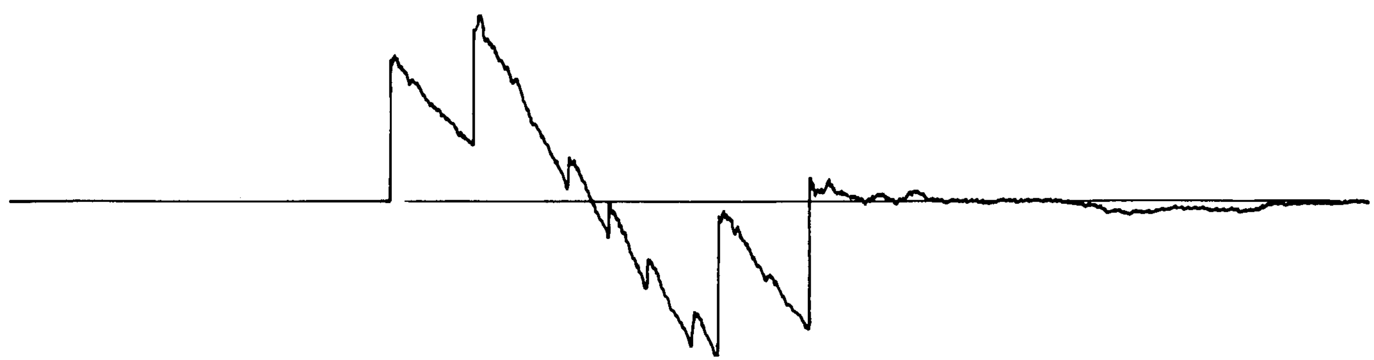


(b) Microphone on 20-foot-high mast.

Figure 9.- Tracings of sample sonic-boom pressure time histories for a high-altitude flight condition of generating aircraft. (Run 1.)



(a) Microphone on ground.



(b) Microphone on 20-foot-high mast.

Figure 10.- Tracings of sample sonic-boom pressure time histories for a low-altitude flight condition of generating aircraft. (Run 14a.)

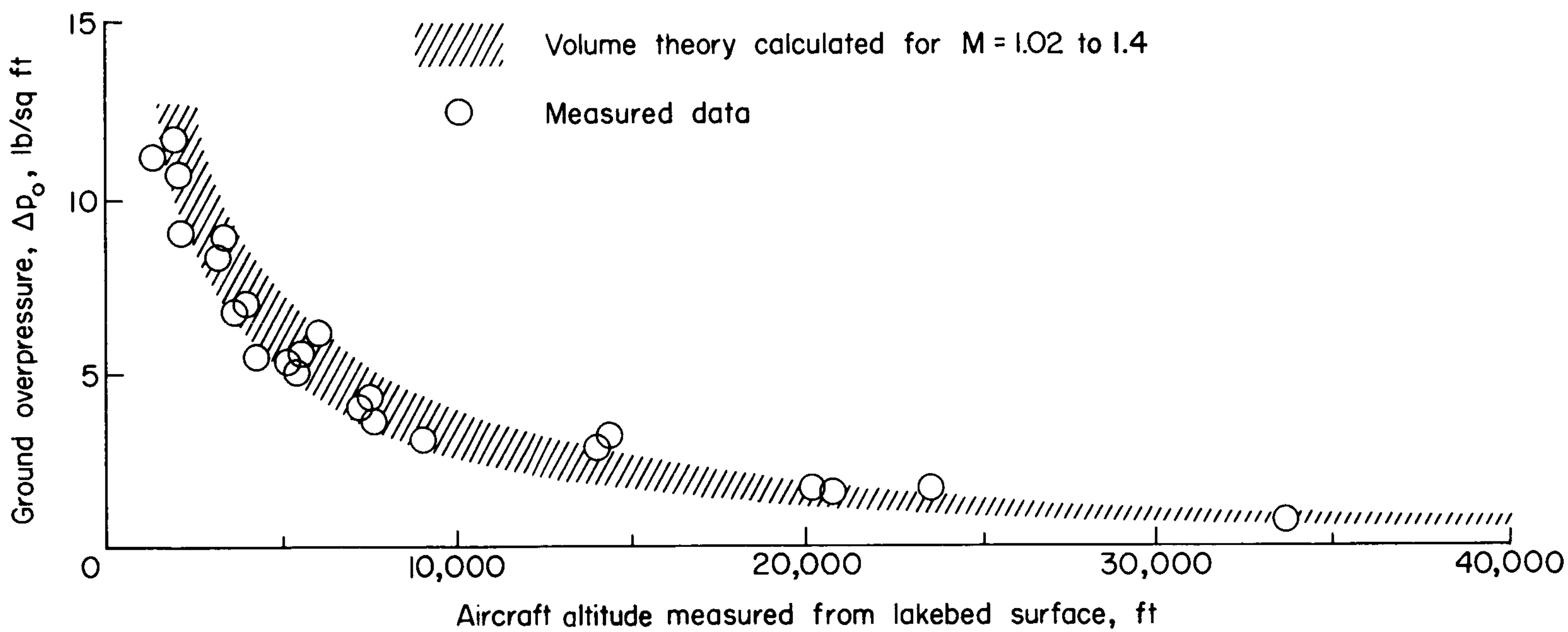
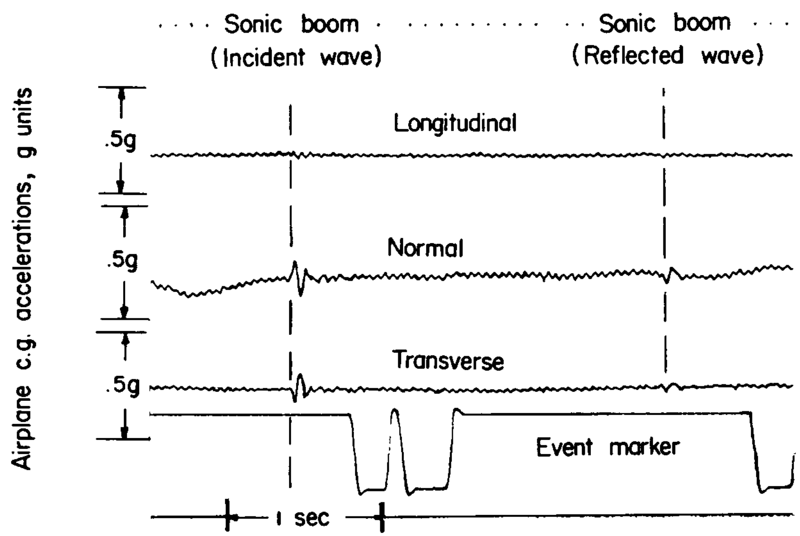
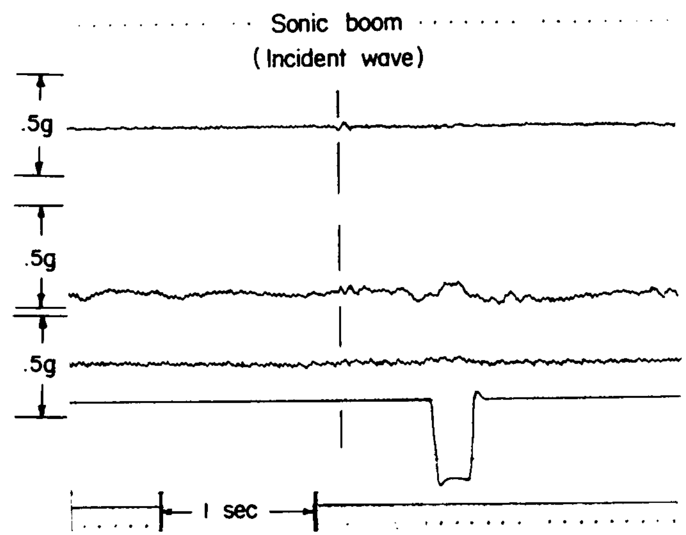


Figure 11.- Comparison of calculated and measured ground overpressures.

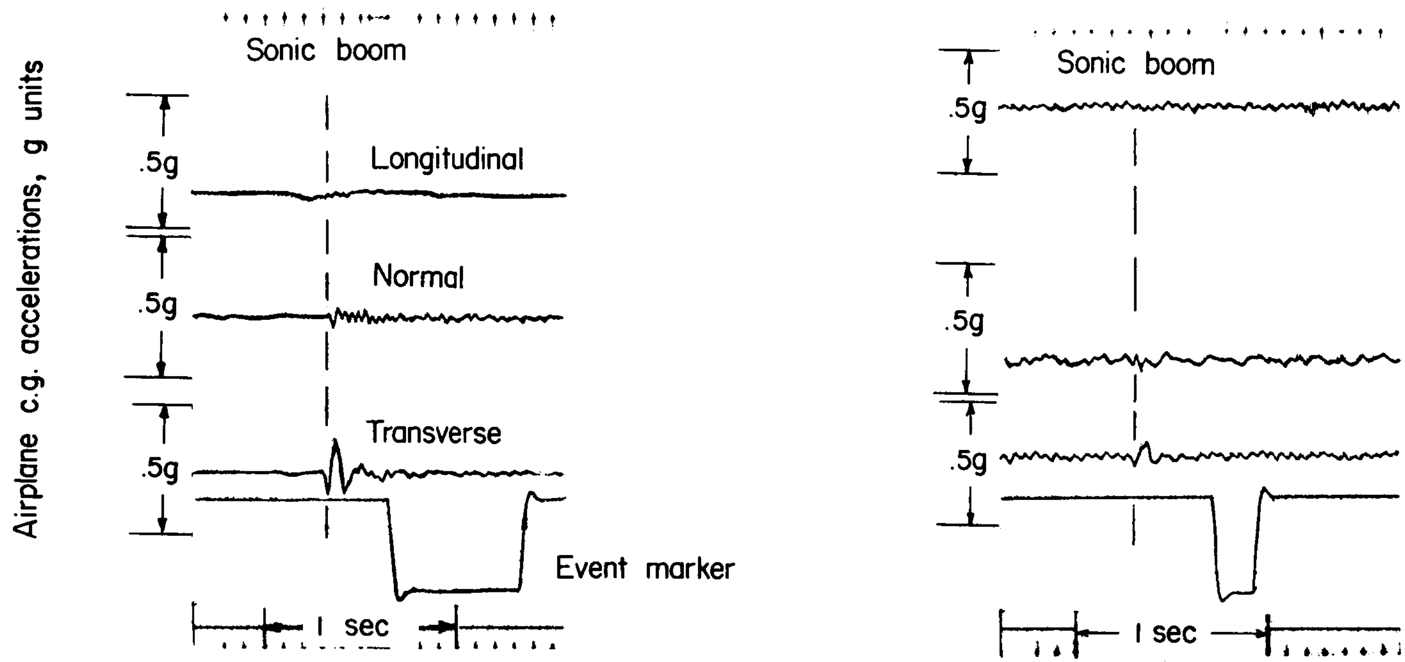


(a) Piper Colt.



(b) Modified Beech C-45H.

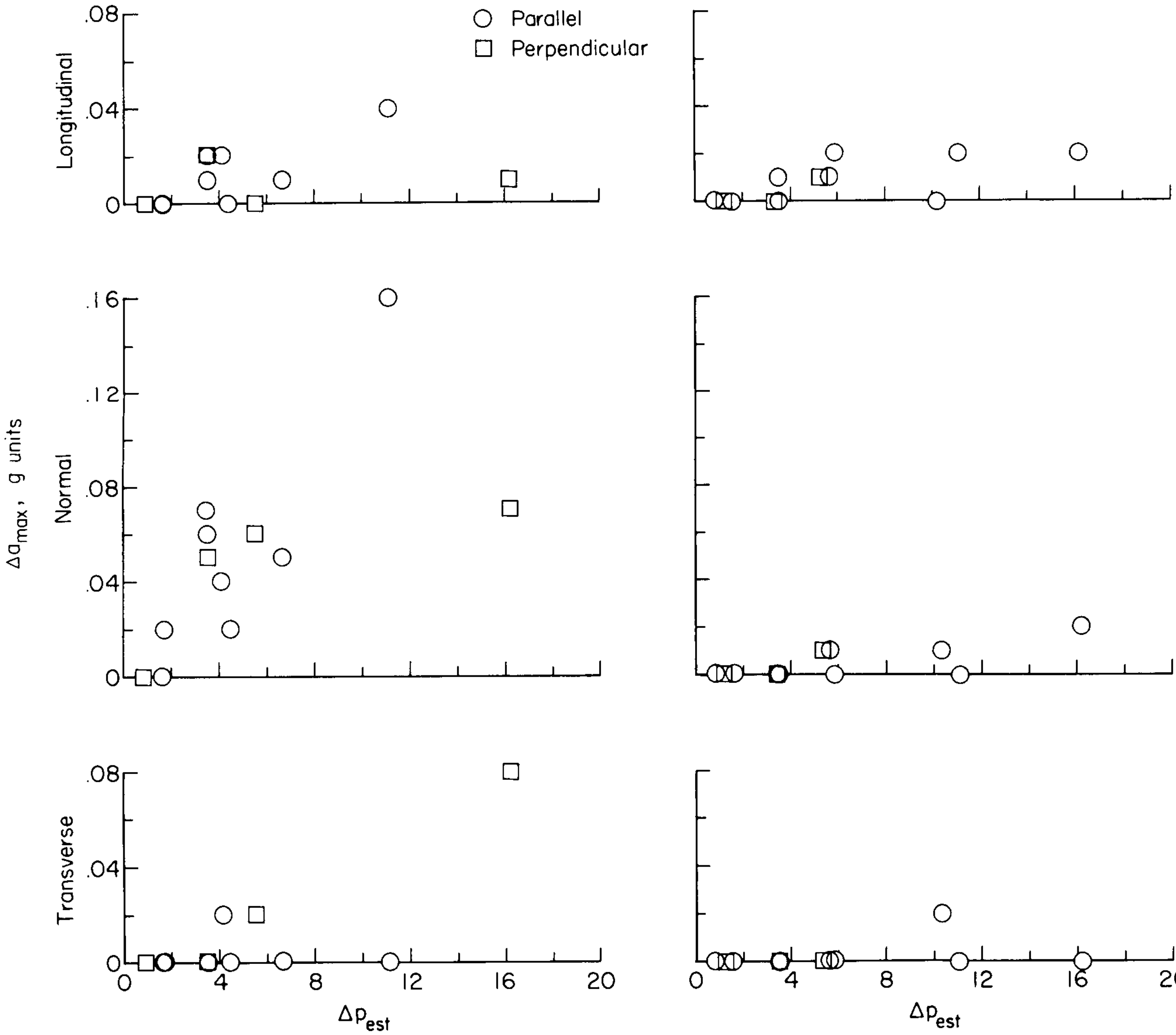
Figure 12.- Acceleration responses of test aircraft to sonic booms while in flight. (Run 14a.)



(a) Piper Colt.

(b) Modified Beech C-45H.

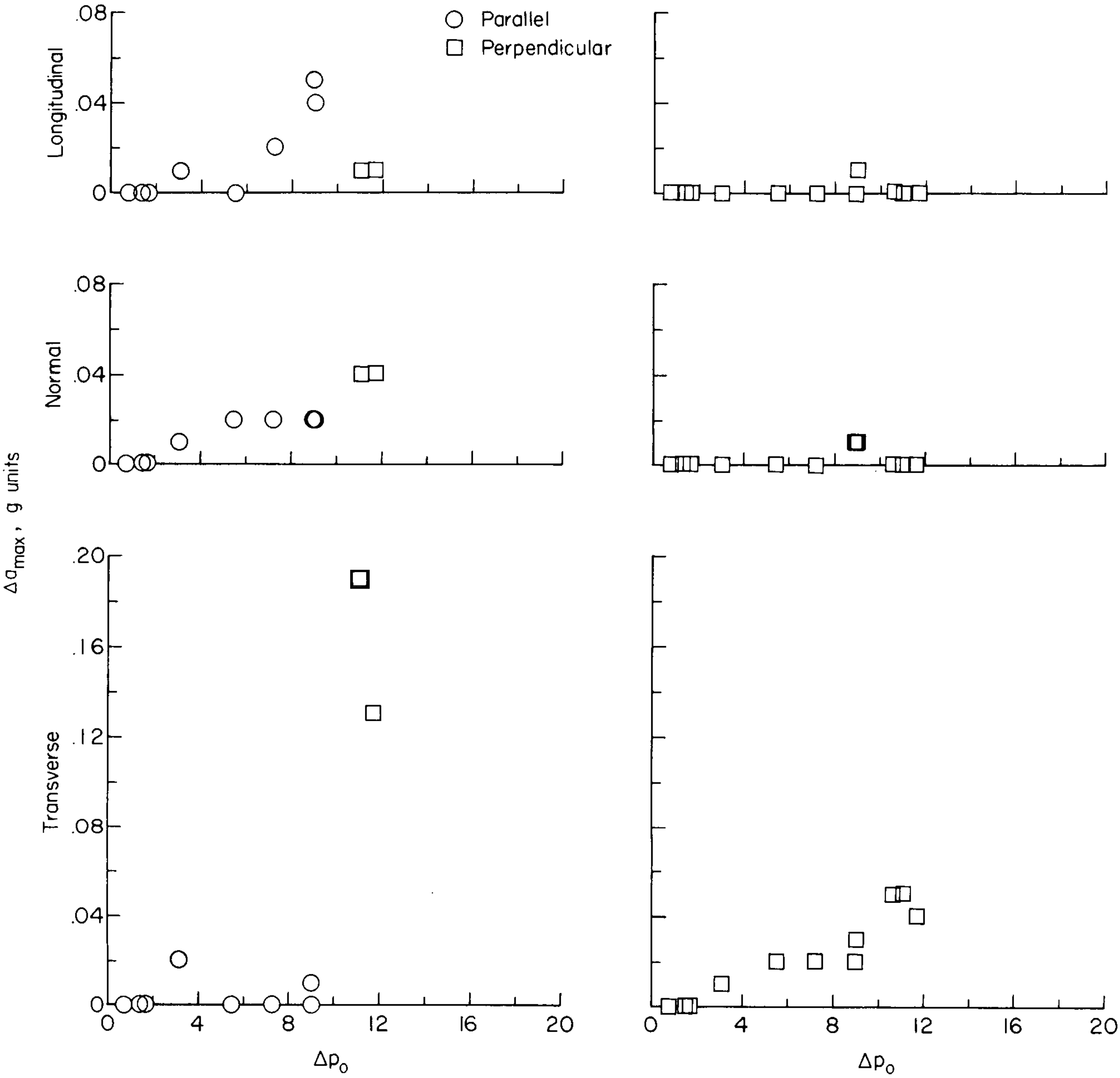
Figure 13.- Acceleration responses of test aircraft to sonic booms while on the ground. (Run 10a.)



(a) Piper Colt.

(b) Modified Beech C-45H.

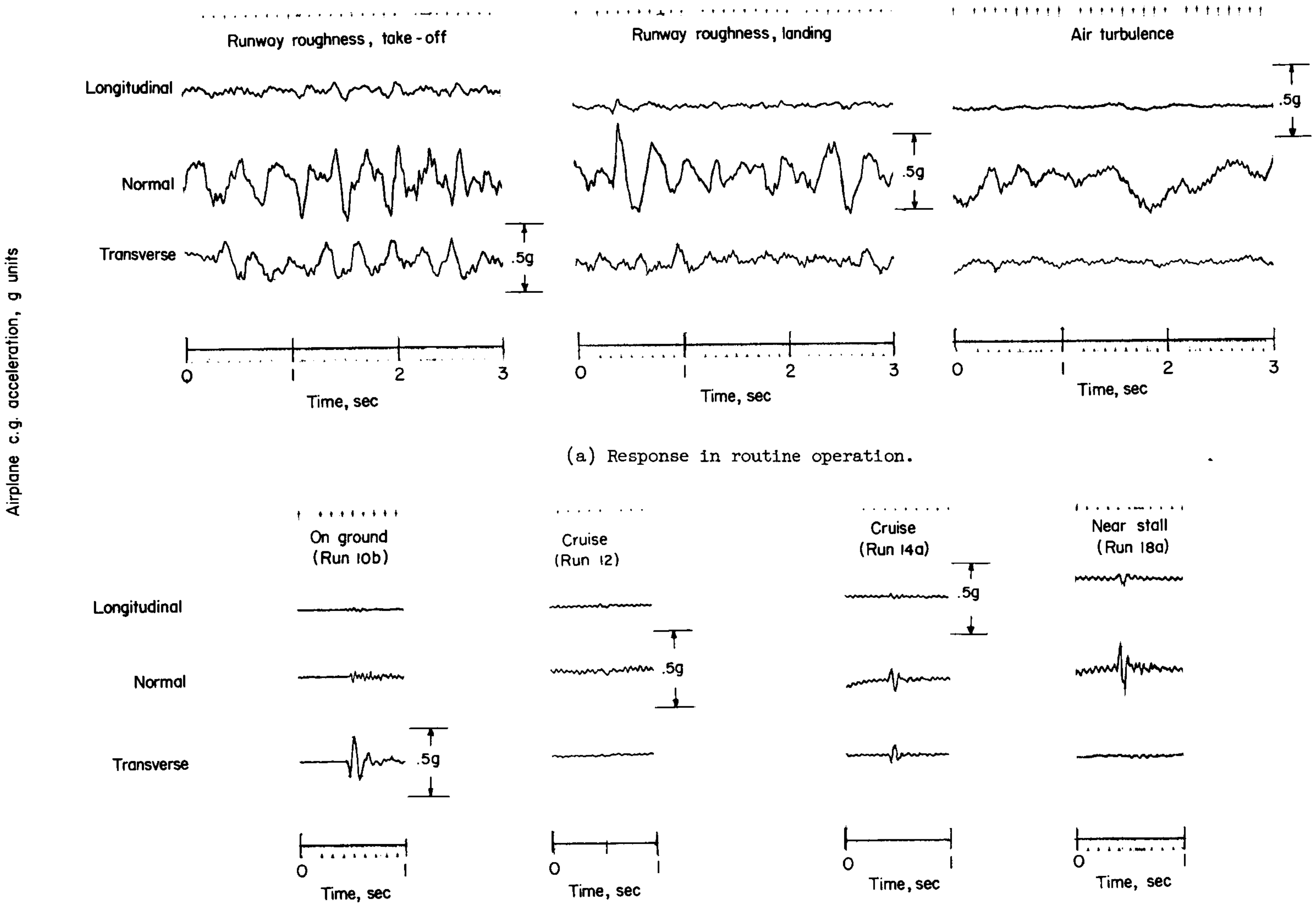
Figure 14.- Maximum airplane in-flight acceleration responses due to sonic-boom overpressures.



(a) Piper Colt.

(b) Modified Beech C-45H.

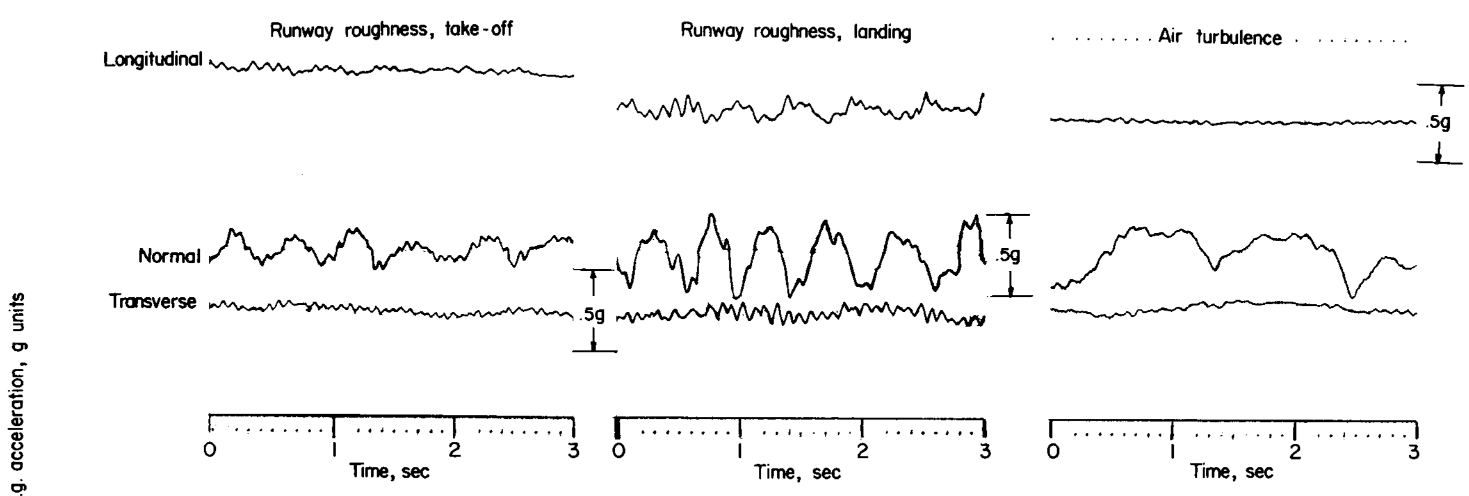
Figure 15.- Maximum airplane on-ground acceleration responses due to sonic-boom overpressures.



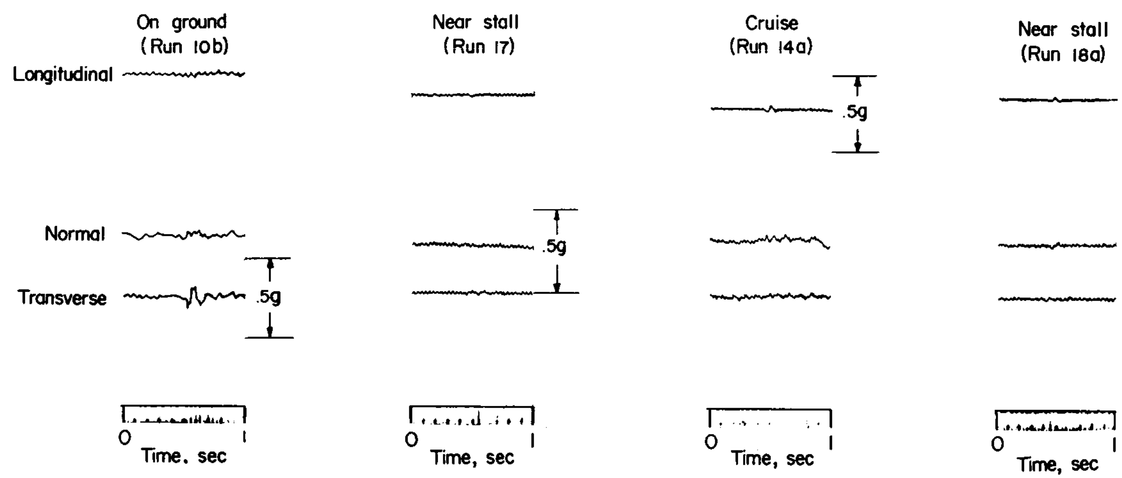
(a) Response in routine operation.

(b) Response to sonic boom.

Figure 16.- Comparison of response of Piper Colt airplane to sonic boom with response to runway roughness and air turbulence.



(a) Response in routine operation.



(b) Response to sonic boom.

Figure 17.- Comparison of response of Modified Beech C-45H airplane to sonic boom with response to runway roughness and air turbulence.